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BREEDING CHICKENS FOR MEAT PRODUCTION

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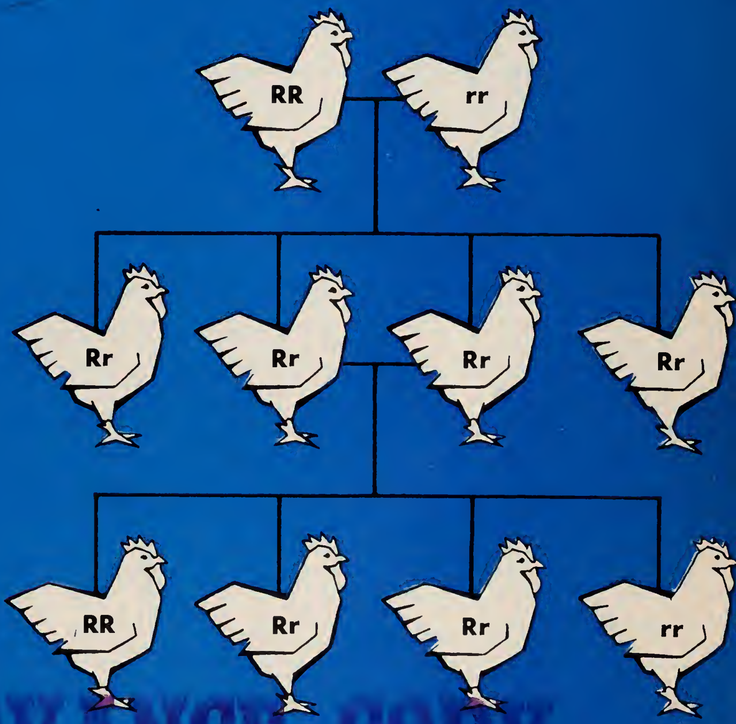

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This Bulletin

reviews a considerable amount of literature that has been issued on the subject of breeding chickens for meat. It interprets the other literature in the light of conditions found in California.

Genetics is a complicated subject and difficult to talk about in other than scientific terms. While popular terms have been used where possible in this bulletin, it may still be somewhat too technical for any but commercial poultry breeders.

Experimental results in the field of breeding chickens for meat production are, as yet, fairly limited. The information in this bulletin should, however, help commercial poultrymen to set up efficient breeding programs that will raise the general level of meat production of their flocks.

Starting on page 35 is a list of books, pamphlets, etc., which are cited in this bulletin and an annotated list of recent literature recommended to those who wish to know more about the subject of breeding chickens for meat production.

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In an Eggshell . . .

If this is done	This can be expected
Mass Selection	
Use the individual excellence of the birds as a basis for breeding—choosing the birds on appearance.	Limited improvement. Appearance of the bird is not always a criterion of genetic background. Will help improve traits of high heritability.
Pedigree Breeding	
Select breeding stock on basis of characteristics exhibited by ancestors.	General improvement, but limited by the fact that the heritability of many good qualities is low. May be better than mass selection.
Family Selection	
Select breeding stock on the basis of average performance of offspring of sire and dam.	More precise improvement. May include progeny or sib testing.
Growth Rate	
Select breeding stock that shows rapid growth rate to the desired age.	More rapid marketing—less feed required to attain desired size.
Conformation	
Use as breeding stock birds with desired conformation at marketing age—not necessarily at maturity.	More acceptable birds, from the standpoint of consumer preference.
Breast Width	
Use breast width as a fairly good indication of meat on the bird.	Same as above.
Rate of Feathering	
Select for rapid rate of feathering.	Less possibility of unsightly and hard-to-pluck birds at marketing time.
Crossbreeding	
Crossbreed different breeds or varieties within breeds.	Usually, but not always, more vigor of growth in the crossbred progeny. Sometimes earlier sexual maturity will result also.

For a better understanding

of the material in this bulletin, the following is an explanation of some of the primary factors governing heredity, and a glossary of a few of the terms used in genetics.

Inheritance of characteristics is based on the transmission of genes from parent to offspring.

Genes are defined as the determiners of hereditary characters. With few exceptions, they occur in pairs—one member of the pair being derived from the sire, the other from the dam.

Thus genes may be:

Dominant, or recessive. A dominant gene will express itself whether or not the gene paired with it is like itself or different. A recessive gene will express itself only when both members of the pair are alike. This is best explained by an example.

A purebred rose-combed bird has 2 dominant genes for the expression of rose-comb. A single-combed bird has instead 2 recessive genes. A chicken resulting from a cross between such birds will receive a recessive gene from one parent and a dominant gene from the other, and will exhibit a rose comb.

If 2 such crossbred birds are mated, their offspring will consist of both rose- and single-combed birds in a ratio of 3 rose-combed birds to 1 single-combed. Of the rose-combed birds in this generation, one-third will be:

Homozygous. That is, they will have acquired 2 like genes and will breed true. The other two-thirds of the rose-combed birds in the second generation will be:

Heterozygous. They will have acquired 2 unlike genes and will not breed true. See chart on page 5.

Various genes are usually designated by arbitrary letters—capital letters designating dominant and small (lower case) letters designating a recessive condition. Thus the gene for rose comb (a dominant) is represented as *R;* the gene recessive to it and producing a single comb when homozygous, by *r*.

Genotype is the term designating the constitutional makeup of an individual with respect to genes. Using letter symbols explained above, the genotype of a purebred rose-combed bird (which is homozygous) would be *RR;* that of a single-combed bird would be *rr*. A crossbred bird (heterozygous) would have a genotype indicated by the symbol *Rr*.

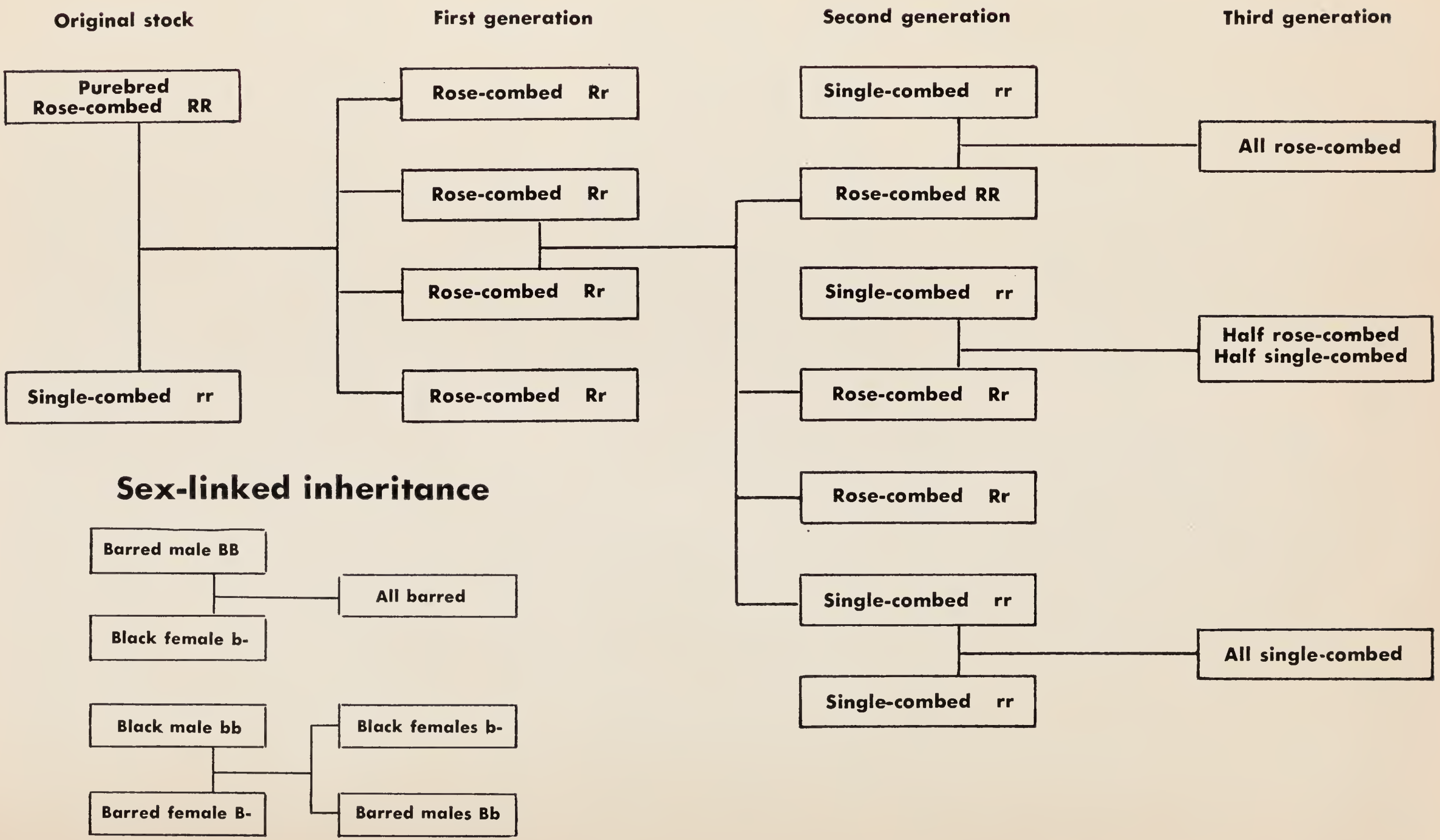
Phenotype is the term used to indicate the visible characteristics of a bird's constitutional makeup, or genotype. In the example used above, there are only 2 phenotypes—rose-combed and single-combed. Birds having *RR* or *Rr* genotypes will exhibit the rose-combed phenotype; birds having the *rr* genotype will show the single-combed phenotype.

The only way to distinguish between the genotypes that show the rose-combed phenotype is by breeding tests. If a rose-combed bird, bred to a single-combed bird produces only rose-combed offspring, then it must have the *RR* genotype; if it produces some single-combed offspring, it must have the *Rr* genotype.

Incomplete dominance is used to designate cases in which 2 unlike genes are present in a pair governing a character, but neither gene completely suppresses the expression of its mate. When this occurs, the mating of 2 such heterozygous indi-

(Continued on page 6)

Gene transmission



Breeding Chickens for Meat Production

Commercial broiler production in California has increased steadily

The number of chickens raised in California increased, according to census reports, by 6 million birds, from 1934 to 1939, and by over 8 million from 1939 to 1944. A high percentage of the birds raised are retained for layers, but most of these are eventually sold. Thus much of the poultry marketed in California is a by-product of the market-egg industry.

Commercial broiler production has increased fairly consistently (fig. 1). Despite increases in the number of chickens raised, it is obvious that the percentage of commercial broilers of the total chickens marketed has gone up steadily.

The gain in broiler production and the increased replacement of pullets as needed has spread hatches more uniformly throughout the year (fig. 2). Leghorns accounted for about two-thirds (67.6 per cent) of all laying flocks, with 80.7 per cent of the larger flocks (over 3,200 birds in a flock) being Leghorns. In flocks under 3,200 birds, there were 62.7 per cent Leghorns, 12.5 per cent New Hampshires, and 24.8 per cent crossbreds and others.

While comparable data for earlier years are not readily available, it seems reasonable that these estimates for about January 1, 1949, by the California Crop and Livestock Reporting Service, indicate an increase in heavy breed breeding flocks. This assumption is strengthened by the Service's estimate that 72 per cent of the commercial broilers marketed were heavy breed crossbreds. Moreover, the number of commercial broilers (as a percentage of all birds raised) increased from about 8 per cent in 1935 to about 40 per cent in 1948.

Grades. There are 3 quality grades for live chickens, based on the quality of the bird and absence of accidental blemishes. Here they are in abstract.

A or No. 1: Bird is healthy, well feathered, may have a slight scattering of pinfeathers, is of normal physical conformation. Slightly curved keel, ⅛-inch dent in keel and slightly crooked back is permitted; well developed, moderately

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viduals produces 3 phenotypes in the offspring which correspond to the 3 genotypes present.

In cases where characters are produced by the action of a large number of genes, the result is said to be due to **multiple genes.**

Sex-linked inheritance can probably be best explained by an example. A simple sex-linked character in poultry is the barred plumage of the Barred Plymouth Rock. When a male of this variety is crossed with a black female, all the progeny is found to be barred. In a reciprocal cross, however, when a black male is mated to a barred female, in the first generation, the females are found to be black, while the males are barred. Sex-linked crosses for early sex identification are based on this principle.

The reason for the behavior of the sex-linked genes lies in the fact that the male possesses a paired complement, as in the case of all other genes, while the female has only one member of a sex-linked gene pair. Thus the male genotype in the case of the pure Barred Plymouth Rock is *BB*, while the female genotype is *B*–. In the case of the black birds, the male's constitution is *bb* and the female's *b*–. In the second cross as described above, *bb* × *B*– (black male × barred female), the male progeny will be heterozygous barred (*Bb*) and the females will be black (*b*–).

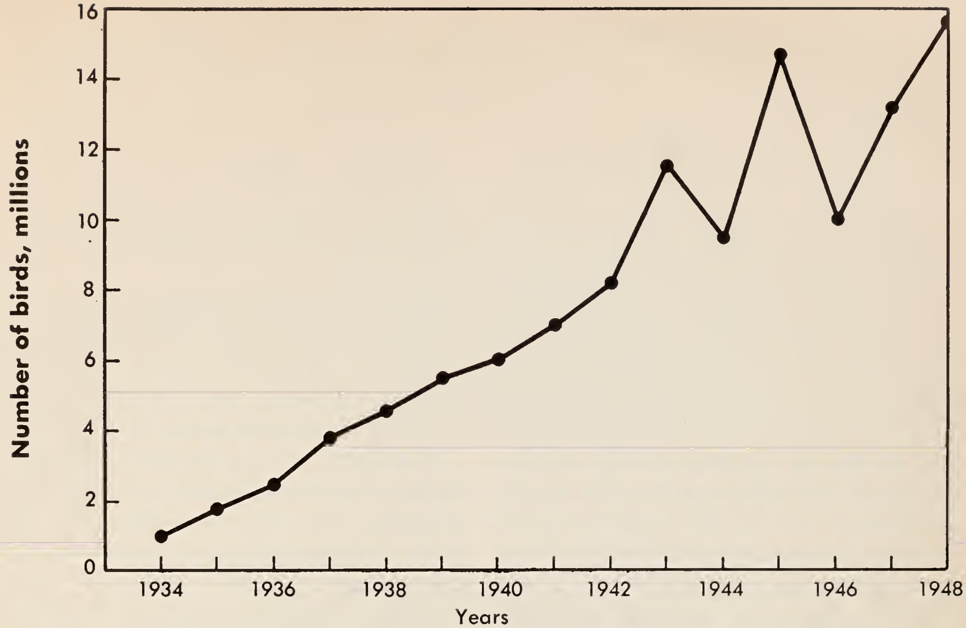

Fig. 1. Commercial broiler production in California between the years 1934 and 1948.

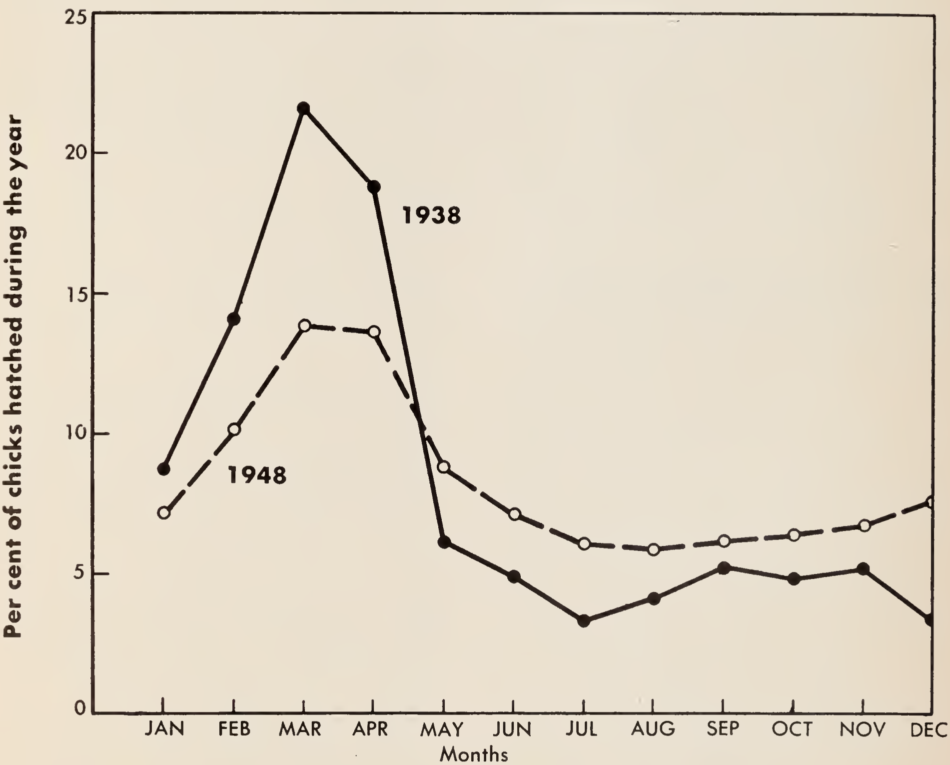

Fig. 2. Hatchery sales in California in 1938 and 1948. Note the increase in sale of baby chicks during the summer and fall months in 1948. This is due to hatches being more uniformly spread throughout the year.

broad and long breast, well fleshed on breast, thighs and back; fat on breast, back, hips and pinbones in young birds and well-covered old birds; free from tears and broken bones but may show minor defects.

B or No. 2: Bird is healthy, fairly well feathered; has normal conformation, but may have slightly curved keel, moderately crooked back and slightly misshapen legs and wings; fairly well fleshed; sufficient fat to partly cover flesh, with excess fat permitted in hens; free from tears and broken bones, but may show blisters, etc.

C or No. 3: Applies to birds that do not meet the specifications for U. S. Grade B.

Color preferences. Well-fleshed and feathered fryers of the yellow-skinned colored breeds are preferred in California, but no premium is paid for yellow-skinned birds nor deduction made for white-skinned birds. A higher price per pound is usually paid for colored than for white-plumaged birds. This unjustified discrimination is one of the reasons why White Plymouth Rocks and other white-plumaged birds have failed to become popular in California although they are widely used in other states for broiler, fryer, and light roaster production.

These are the requirements for meat birds on California markets

The requirements for meat birds on California markets are, with the exceptions noted below, those common to meat birds wherever marketed. For that reason the classification and tentative specifications adopted by the Bureau of Agricultural Economics, United States Department of Agriculture have been followed, with slight modifications in the minimum ages of fryers and roasters to allow for more rapid growth commonly obtained in specialized fryer production. Exact classifications differ on the various markets; for example, all birds weighing from 2 to 4 pounds may be referred to as fryers on some markets. Dressed chickens are classified according to kind, age, sex, and weight as follows:

Young birds

Broilers. Young chickens, approximately 8 to 12 weeks old, of either sex, weighing not over 2½ pounds and sufficiently soft-meated to be cooked tender by broiling.

Fryers. Young chickens, approximately 9 to 20 weeks old, of either sex, weighing more than 2½ but not more than 3½ pounds, and sufficiently soft-meated to be cooked tender by frying.

Roasters. Young chickens, approximately 4 to 9 months old, of either sex, weighing over 3½ pounds, and sufficiently soft-meated to be cooked tender by roasting.

Stags. Male birds, of any weight, with flesh slightly darkened and toughened and with comb and spur development showing the bird to be in a state of maturity between that of roasting chickens and cocks.

Capons. Unsexed male birds weighing over 4 pounds, usually 7 to 10 months old, and with soft tender flesh.

Old birds

Fowl. Mature female birds of any age or weight.

Cocks. Mature male birds of any weight, with darkened and toughened flesh.

Hens culled from the laying flocks are marketed as fowl, while surplus Leghorn cockerels are marketed as "broilers." Most of the birds produced especially for meat are raised to fryer or light roaster size, or to about 3 to 4 pounds. On some markets, such as New Orleans, a 2-pound broiler is preferred, but in California, fryers are preferred, although there is little difference in the price paid per pound for fryers and for broilers.

Poultry are also classified in other ways according to methods of preparation and handling of the birds prior to their sale to the consumer.

Establishing a breeding program involves knowing the principles of selection

There are essentially five steps in the development and application of a breeding program:

1. Development of methods of measurement of the characteristics of individuals.

2. Determination of the characteristics and measurements of the ideal type.

3. Actual measurement of individuals.

4. Analysis of the individual records on basis of the group they belong to (family, strain, or breed).

5. Selection of superior representatives to be mated.

In breeding chickens for meat production, the greatest difficulty has been the first two steps. Yet they are both indispensable. At the present time, makeshift substitutes are being used and rapid progress in the improvement of meat birds cannot be expected until further knowledge is acquired. Many ideas exist as to what characteristics an ideal meat bird should possess. In the majority of cases, these ideas are purely subjective. They can be illustrated on actual birds, but cannot be translated into the language of measurement. In a character such as egg production the number of eggs laid by a bird in a given period of time represents a figure which can be used for comparison with other birds. In the case of meat type such an index is not available. This in part may be attributed to the failure of the packing industry to provide the breeders with sufficiently precise specifications, but largely it is because of the complexity of the problem involved. Some research work is being done at present on just what constitutes a superior dressed carcass and how to recognize it in a living bird. When a practical solution is obtained for this problem the work of the meat breeder will be much simpler. What is definitely needed is the determination of the typical measurements and characteristics of birds which approach the ideal agreed upon. These measurements must, of course, reflect the visual appearance, the percentage of edible flesh, and the growth of the birds.

The third step of the breeding program represents the actual application of the first two steps.

The methods used in the fourth and fifth steps outlined are common to all breeding programs. The type of procedure depends on the level of operation. Thus the commonest and earliest method used is that of mass selection. In a more advanced stage the consideration of ancestry of individuals selected for breeding is also needed. This may be designated pedigree breeding since it involves the identification of stock hatched and the keeping of pedigrees. Finally, the most complex breeding stage is that comprising family selection and progeny testing. Each of the successive stages implies the use of the methods of the earlier stages and, in addition, the use of special methods for the higher level of breeding operations.

Mass selection. In this method the selector chooses the best of his birds to mate with each other. The individual excellence of the birds selected is the only criterion used and nothing has to be known about the origin of the birds, nor whether they transmit their desirable characteristics to their offspring.

It is obvious that with many characters improvement under this system of breeding is very uncertain. The appearance of the bird does not always correspond to the inherited factors which the bird possesses. Thus, two white birds mated may yield colored progeny. The appearance of the bird (its *phenotype*) does not necessarily correspond to the inherited factors which the bird possesses (the *genotype*) and transmits to his or her offspring. Consequently, selection on the basis of the phenotype does not neces-

sarily lead to the results obtained by selection on basis of the genotype. On the other hand, there are characters easily improved by mass selection. They are traits in which the correlation between the phenotype and genotype is relatively high—traits that have a high degree of heritability.

In addition to the method involving the mating of the best to the best, another type of breeding which is often used is that of compromise mating. This involves the use of birds excelling in one or more characters to be mated with birds which are deficient in these characters but which possess other superior characteristics which may possibly be lacking in their mates.

Pedigree breeding. At the next level of breeding procedure, an attempt is made to evaluate the genotype of the birds selected. Since the genotype cannot be determined from the bird's appearance, reliance has to be placed on breeding performance either of the bird itself or of the bird's ancestors. It is the latter type that is involved in the simplest form of pedigree breeding.

When the characteristics of the parents of a bird are known to be desirable and the bird itself duplicates these qualities, one is justified in assuming that the probability of the given bird carrying concealed undesirable factors in its genotype is less than when no information on the ancestry is available. If information on more than one generation is on hand, such probability is further reduced. The principle of selection at this stage is that the birds used in mating should show an uninterrupted lineage of desirable ancestors. It was this method of selection that has resulted to a great extent in the improvement of most domestic animals, including poultry. It must, however, be clear that this method provides only an estimate of the knowledge of the bird's genotype. Full sisters and brothers differ both in phenotype and genotype, due to segregation of genes. The simple form of pedigree breeding where selection is made on basis of ancestry does not take account of this fact.

Family selection and progeny testing is based on an estimate of breeding worth and on the actual performance of the progeny of a given mating. Whatever the phenotypes of two mated birds, if they have desirable genotypes, they will produce superior offspring. It is generally more likely that a superior phenotype is associated with a superior genotype. A desirable looking bird may have a desirable or an undesirable genetic constitution; a bird lacking in desirable characters will seldom have a superior genotype. Hence, the problem of the selector in this breeding phase is to test the superior appearing individuals for their genetic constitution. If they carry the desirable genes, their offspring will exhibit the desired qualities. Such breeding birds may then be remated as long as they reproduce themselves efficiently. Their offspring in turn can be progeny-tested and the operation repeated as long as a breeding program is carried on.

Another form of family selection involves the sib test. The word *sib* is used to indicate brothers and sisters when distinction as to sex is not important. Thus all of the offspring of a given male mated to a given female are designated in relation to each other as sibs or siblings. It should be apparent that when a bird has uniformly good sibs, it is likely that the genotypes of the parents were superior (the sib test of a bird is at the same time the progeny test of the parents). The superior sibs may be subjected to a progeny test themselves if desired.

It should be noted that in the transition from the second to the highest level of breeding a shift in emphasis has been made. In mass selection and in the simpler form of pedigree breeding it was the *individual* that was considered; in the progeny and the sib tests the *family* as a whole is being evaluated.

The word "family" is used here to designate a group of sibs. The term "sire family" may be used to denote the offspring of one male and several females (full- and half-sibs).

The key to this shift in emphasis lies in the segregation of genes, as mentioned before. Since no given individual is likely to breed true for all of the many characters which make a superior bird, there is always segregation in its offspring. Accordingly, the offspring vary in degree of excellence, but by considering their average worth, a fair estimate of the genotypes of the parents may be obtained. It follows clearly that the larger the family, the more accurate is such an estimate.

There are, however, two qualifications in this general rule. First, it can be shown statistically that the reliability of the estimate depends not on the number of individuals but on the square of that number. This means that to double the precision of the estimate a fourfold increase in number of progeny is necessary; to triple the precision of the estimate, the number of offspring must be increased ninefold, and so forth. Secondly, an increase in the number of progeny raised means that the hatching season has to be lengthened. In the case of characters affected by date of hatch (such as rate of growth, sexual maturity, see page 17), the environmental or nonhereditary variation is increased. Unless this added variation is corrected for or taken into account, the variability in the characteristics of a family becomes too great for an adequate genotype analysis. Thus a compromise must be reached between increasing nonhereditary variability by lengthening the hatching season and decreasing the number of progeny tested from each mating in a shorter season.

Degrees of heritability are shown in different characteristics—some have high and some low heritability. For traits having high heritability, individual selection of birds can be efficient in raising the average level of performance. For traits of low heritability, resort to family selection must be made. In both situations, combined selection using information on both individual and family traits will make for a more reliable breeding program than would reliance on either method alone.

Below is a list of some of the traits for which information on the degree of heritability is available.

To summarize the discussion on selection, it may be said that an efficient breeding program comprises primarily the recognition of individuals of superior worth in the sense of their ability to transmit desirable characters to their offspring, and of mating such individuals to produce a desirable combination of characters in the next generation. A non-trap-nesting breeder or multiplier relies on the visual appearance of the birds for identification of superior stock. This method is not so efficient as the one employed by a trap-nester who can marshal the information about the ancestry and the progeny of the birds concerned to aid him in the procedure of such identification.

The multiplier makes new selections every year. The trap-nesting breeder is

High heritability	Intermediate heritability	Low heritability
Body weight	Survivors' egg production	Hen-housed egg production
Growth rate	Shell thickness	Viability
Rate of feathering	Sexual maturity	Specific resistance to lymphomatosis
Shank length	Breast width	
Egg weight	Keel length	

able to repeat successful matings of previous years and to utilize the better families and strains generation after generation.

Both the multiplier and trap-nest breeder must keep records. The problem of the fryer breeder, for instance, is to produce birds which are of superior quality at the time of marketing for fryers. Since it is not possible to tell by looking at an adult bird whether it was early or late feathering, rapid or slow in its early growth, records must be made on the prospective breeding birds at the appropriate ages with respect to such characters. The breeder who pedigrees his stock is able to identify the individual birds by means of wing bands. The multiplier or nonpedigreeing breeder must use a scheme of leg banding to insure that the identity of the superior birds at the marketing age will not be lost before the birds are ready for breeding.

These are the problems that are common to all breeding programs

Any sound poultry breeding program must take into consideration the fundamental factors of hatchability, egg production, and viability (ability to live). All of these affect the number of birds that can be produced, and a high level of all three is essential for efficient production. As is the case with any character, the actual hatchability, egg production, and viability observed in a flock are the results of interaction of both heredity and environment. Sound feeding and managemental practices are prerequisite to any production program. In all of the present discussion this is implied and no specific repetition of this fundamental point will be made, with a few exceptions (see, for instance, the discussion of crooked keels).

The basic difficulties in breeding for improved hatchability, production, and viability lie in the complex nature of all of the characters. Thus, hatchability is influenced by many genes, acting perhaps at different times in the course of the embryo's development. Selection against genes which cause embryo mortality may be necessary in flocks where such genes occur. Egg production is also not a unit character: early maturity, lack of winter pause, high rate, lack of broodiness, and high persistency may all have to be selected for to insure improvement in egg records. Similarly, the factors for viability may be specific; that is, selection against mortality from neoplastic diseases (fowl paralysis, tumors, iritis, and associated conditions) will not necessarily lower mortality from other causes.

An elementary selection program may use as a standard of selection the net result of the action and interaction of all these various factors. Thus, a breeder may use the percentage of hatchability, the average egg production and the percentage survival as the only bases upon which he selects breeding birds. Such a program may lead to improvement, but an attempt to analyze which of the particular characters is the limiting factor in the breeder's progress may be helpful. For instance, a given family average production may be low because of late maturity; another family with the same average record may exhibit low rate of production. By identifying such component factors, a breeder is enabled to exercise much more intelligent judgment in making up matings, than he can in the more elementary procedure, and progress should be faster.

The same principle holds for meat production. A breeder may select on the basis of a total quality estimate of a family or strain. He may also consider the particular factors which are responsible for the differences in quality between groups of birds. There are also differences in efficiency of production and in yield, as well as in quality. The fundamental problem

for the meat breeder then, is to be able to identify the bases of these differences. So far as the inherited factors are concerned, economic production of a large number of birds of superior quality depends, in addition to hatchability, egg production, and viability, on such characters as growth rate and pattern, conformation, rate of feathering, and freedom from defects. These, together with a number of other pertinent characters, will be discussed in the following section.

And these are the factors that affect quantity and quality of meat

Much technical information has been gathered concerning the factors that affect meat quantity and quality. Some of these factors are of great importance and deserve careful study. Others are of negligible importance. The amount of work done has not always been in proportion to the need for information about a particular factor; hence, we have much corroborative or contradictory information about some phases and little about others. The following discussion naturally reflects these discrepancies in our knowledge of the subject.

Chick weight. The weight of the newly hatched chick depends primarily on the weight of the egg from which it hatched. The correlation coefficients measuring this relation reported in the literature vary from $+ 0.73 \pm 0.013$ (Benjamin, 1920) to $+ 0.95$ (Graham, 1932). Galpin (1938) found small but significant variations in the correlation between egg and chick weight at different seasons, although the seasonal changes in chick weight resulted at least partly from changes in egg weight. Halbersleben and Mussehl (1922) reported that chicks weighed on the average 64 per cent of the weight of the eggs. It is thus obvious that the weight of chicks cannot be expected to exceed two-thirds of the weight of the eggs set.

When the weights of day-old chicks from different hens are grouped together, no statistically significant difference can be demonstrated between the weight of males and females. Munro and Kosin (1940) have, however, shown that the males weigh slightly more than the females by comparing the weights of chicks of the two sexes from the same hen and in the same hatch.

Initial chick weight has no influence on the rate of growth of chicks up to 8 to 20 weeks of age. The weight of the chick about 24 hours after it hatches is therefore of no importance to the producer of broilers or fryers, provided the chicks were hatched under normal conditions. If the chicks are small, because the humidity was excessively low or the temperature too high, this may result in too great a mortality among them. Such conditions usually also result in low hatchability and, therefore, should be carefully avoided.

While the weight of day-old chicks is of little practical importance so far as the fryer producer is concerned, it is nevertheless desirable to produce chicks of average size, weighing about 1¼ to 1½ ounces (35 to 43 grams) each. There are three reasons for this: (1) Small chicks may be out of small strains of birds and may prove slow-growing. Usually, however, differences in the weight of chicks merely reflect differences in the weight of eggs from pullets and hens of different ages. (2) Medium-sized chicks are hatched from medium-sized eggs, which hatch better than eggs that are much below or above the average weight. (3) Average-sized chicks make a better first impression on the buyer than undersized chicks.

Growth rate. The size of an immature animal depends primarily on the length of time the animal has been growing, and the rate at which it grew. Initial

weight in the case of chicks has, as stated, little influence. While there may be inherited differences in the duration of growth between birds of different breeds, strains, or families, the important genetic variable for a poultry meat producer is rate of growth to market age or market weight. Inherited ability to grow fast or slow varies from breed to breed, as well as within a breed. This accounts for size differences at different ages.

There have been many figures published to illustrate this point. Perhaps the most extensive studies on breed differences have been conducted at the Missouri Agricultural Experiment Station. Kempster (1941) has presented the average weights of five breeds of pullets obtained in the course of ten years. It is not desirable to put much reliance on averages based on totals of many hatches produced in different years. Furthermore, Kempster fails to give the number of birds on which the computations are based. Nevertheless, his figures are reproduced in table 1 because they present a typical picture of the course of growth of the pullets of the different breeds. They are, of course, specific to the strains of birds and to the conditions of feeding and management applied to the birds.

The main point to be noted from table 1 is the gradual decrease in gains after the age of 12 weeks. This decrease appears to be related to increasing size and occurs in most strains of birds under ordinary conditions. This is of great importance to the meat producer. As will be shown later, not only do the increments in weight decrease after 12 weeks but the efficiency of gains is consistently reduced with age.

Growth rate may be measured in many different ways. Thus it may be expressed by the formula:

$$\text{Rate} = \frac{W_2 - W_1}{\frac{1}{2}(W_2 + W_1)} \times 100$$

where W_2 is body weight at the end of the period considered, and W_1 the weight at the beginning of the period. This formula may be explained best by assuming that the weight of the bird is equivalent to so much capital increasing at a certain

TABLE 1

Growth of Pullets from Hatching Time to 40 Weeks of Age*

Age in weeks	Single Comb White Leghorn		White Plymouth Rock		Rhode Island Red		New Hampshire		White Wyandotte	
	Weight	Gain†	Weight	Gain	Weight	Gain	Weight	Gain	Weight	Gain
	pounds	pounds	pounds	pounds	pounds	pounds	pounds	pounds	pounds	pounds
0	.09	...	.09	...	.09	...	.10	....	.09	...
4	.41	.32	.39	.30	.41	.32	.48	.38	.44	.35
8	1.01	.60	1.07	.68	1.07	.66	1.25	.77	1.14	.70
12	1.67	.66	1.88	.81	1.89	.82	2.27	1.02	2.10	.96
16	2.20	.53	2.55	.67	2.63	.74	3.17	.90	2.94	.84
20	2.56	.36	3.09	.54	3.19	.56	3.85	.68	3.45	.51
24	2.98	.42	3.59	.50	3.73	.54	4.38	.53	4.03	.58
28	3.26	.28	4.22	.63	4.33	.60	4.89	.51	4.69	.66
32	3.41	.15	4.69	.47	4.88	.55	5.25	.36	5.06	.37
36	3.46	.05	4.92	.23	5.24	.36	5.40	.15	5.22	.16
40	3.50	.04	5.04	.12	5.46	.22	5.54	.14	5.00	—.22

* Data from Kempster (1941).
† Gains are obtained by direct subtractions of weight at previous weighing.

TABLE 2

Average Growth Rates for Barred Plymouth Rocks and Single Comb White Leghorns*

Age	Males			Females		
	Barred Plymouth Rocks	Single Comb White Leghorns	Difference	Barred Plymouth Rocks	Single Comb White Leghorns	Difference
weeks	per cent	per cent	per cent	per cent	per cent	per cent
2– 8	148.6	140.9	7.7	145.6	136.5	9.1
8–16	98.2	90.5	7.7	91.2	82.4	8.8
16–24	33.6	34.3	—0.7	32.6	34.5	—1.9

* Data from Asmundson and Lerner (1934).

rate of interest. If the interest is added to the principal at the end of a given period, what is known as simple interest obtains. If the interest is compounded continuously throughout the period, the compound-interest formula may be used. For the sake of simplicity, one may add the interest once at the moment when the principal plus the interest is halfway between the original and the final capital. The formula given above permits the calculation of the interest rate on this basis. Applying it to growth data on Barred Plymouth Rocks and Single Comb White Leghorns the rate of growth is found to be as expressed in table 2 (Asmundson and Lerner, 1934).

The figures shown are expressed in terms of per cent for the complete period so that it may be said, for instance, that the rate of growth of Leghorn males from 2 to 8 weeks of age was 140.9 per cent. It may be seen from this table that the early growth of the Plymouth Rocks exceeds that of the Leghorns, and that the males grow faster than the females. In the last period of growth the Leghorns actually increased at a higher rate than the Plymouth Rocks, yet in these particular strains at 24 weeks of age the latter outweighed the former by better than 1½ pounds in the case of the males, and by somewhat less than 1½ pounds in the case of the females. This point is of double importance: the early differences in growth rate determine to a large extent final size differences; and the producer of broilers or fryers is particularly interested in adequate early growth, since he desires to market his product at the earliest possible age. An important consideration involved is, however, the fact that within a breed, strain differences may exist which are not necessarily reflected in the final size of the birds. These may be designated as differences in growth patterns and are of great importance. They will be discussed in the next section.

A demonstration of inherent growth rate differences within a breed has been provided by Asmundson and Lerner (1933). Six families of Single Comb White Leghorns from the same flock, raised together under the same management were found to show significant differences with respect to their growth rate from 2 to 8 weeks of age. The three rapid-growing families had a rate of 143.36 per cent, two intermediate families had a rate of 139.86 per cent, and one slow family a rate of 133.21 per cent.

Schnetzler (1936) has demonstrated that such differences may be established by selection. He weighed a group of Barred Plymouth Rock chicks at 8 weeks of age, and when they reached maturity made two matings, one of the fast-growing birds and one of the slow-growing

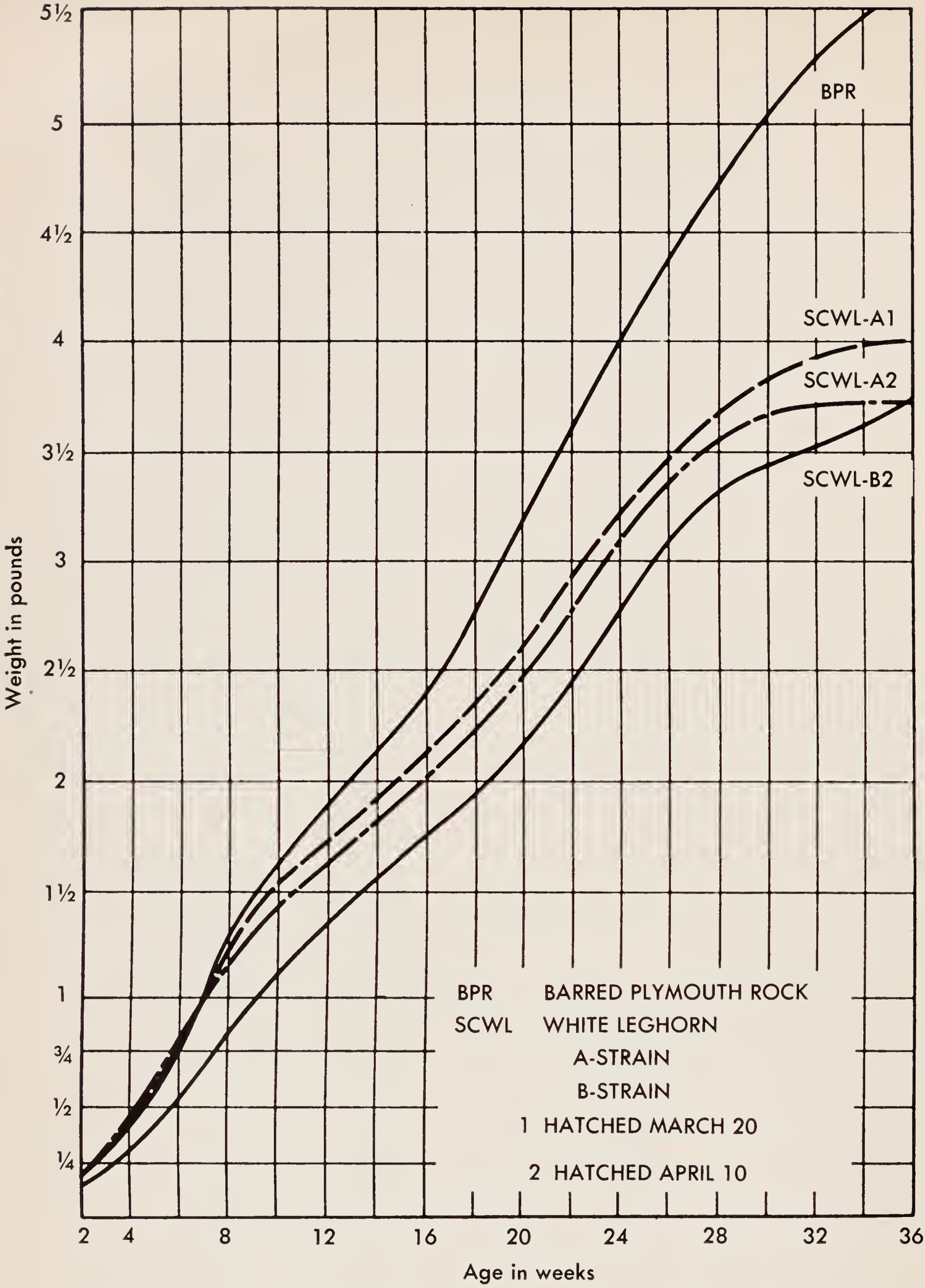

Fig. 3. Growth patterns of Barred Plymouth Rocks and Single Comb White Leghorns. The graph shows differences within breeds and the seasonal effect on rate of growth.

birds. The offspring produced by the two groups showed distinct differences in their weight at 8 weeks of age. This is a clear indication that mass selection within a breed may be effective in producing more rapid-growing broilers and fryers.

Growth patterns. Differences in early growth do not always mean corresponding differences in mature weight. This is a very important point, because it precludes the possibility of using adult weights as standards of selection.

It is possible that birds of the same mature body weight have different growth patterns, reaching their definitive size by different paths. Lerner and Asmundson (1938) demonstrated the existence of such differences within a breed. Two strains of Single Comb White Leghorns were found to weigh the same at 36 weeks of age; yet at 12 weeks they differed by as much as $\frac{1}{4}$ pound (nearly 20 per cent). This is shown in figure 3. In order to distinguish between these two strains the breeder would have to weigh the growing birds. If only the mature weight were considered, the early rapid growth of strain A would not be apparent.

Seasonal effects. Figure 3 also illustrates the effect of season on rate of growth. It has been shown that chicks hatched later in the season do not grow so rapidly as those hatched earlier. In figure 3 this may be seen by comparing the growth of chicks of the same strain hatched in April with those hatched in March.

Data presented by Kempster (1938) show a relation between external temperature and rate of growth, indicating a depressing effect of high summer temperatures, although Galpin (1939) considers that the reduced growth rate of late-hatched chicks is due to effects on the eggs from which these chicks originate.

From the breeder's standpoint the existence of seasonal effects means that proper allowance must be made for time of hatch, since it is obvious that the weights attained at a given age by chicks hatched late in the season will not be comparable or equivalent to weights attained at the same age by earlier-hatched chicks.

In connection with growth patterns and seasonal effects the factor of compensatory growth may be noted. If the growth of chicks is slowed in the early stages by reason of late hatch or other factors, these chicks may exhibit a faster-than-normal rate of growth in later stages. The result is that they eventually reach the same adult weight as chicks which showed no growth reduction. The Leghorns in figure 3 that are designated as strain B exhibited such growth.

Conformation. It is obvious that differences in conformation exist between the various breeds of poultry. Within a breed such differences though less extreme may also be readily seen. The existence of different breeds, representatives of which transmit to their offspring the characteristic breed shape with certain regularity, is a sufficient demonstration of the inherited nature of inter-breed conformation differences. That such differences within a breed are also inherited can be shown by the correlation between body shape of parents and offspring. Figures 4 and 5 (page 18) show how the body shape of Barred Plymouth Rock sires is recognizable in their sons. Because of such relation between the body shape of parents and offspring, improvement in conformation should be possible by selection of breeders of desirable type.

Two difficulties, however, are present. The body shape of a mature individual is not the same as his or her shape at marketing age. This difficulty may be overcome by examination of the prospective breeding birds at different stages of development and selection for breeding of individuals which are of desirable conformation throughout the growing period. As Jaap (1938) has pointed out there are distinct differences between breeds in this respect. The Cornish and Games achieve broad and plump fleshing

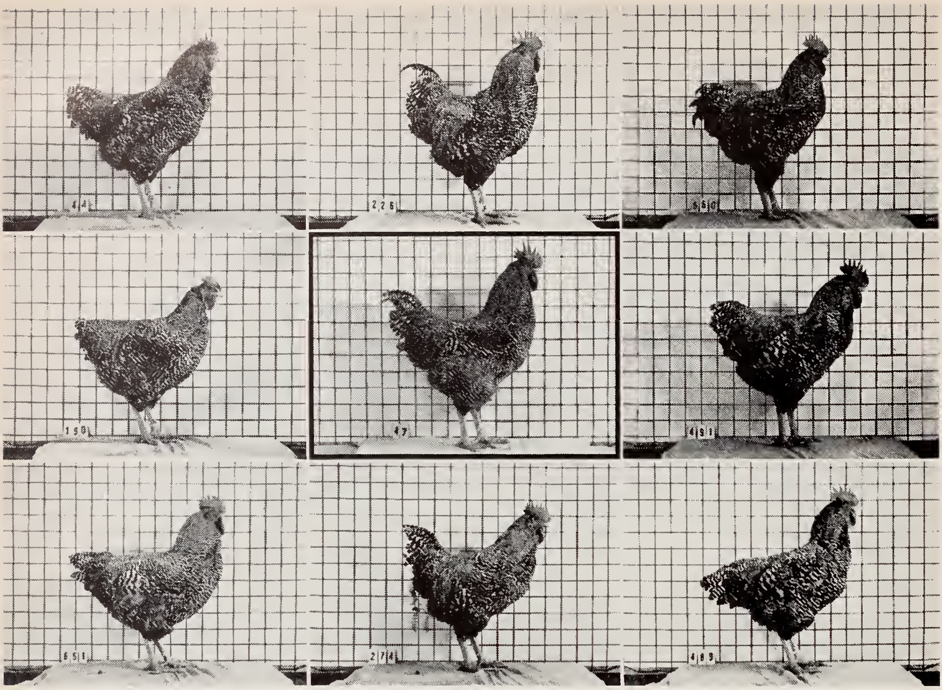

Fig. 4. Hereditary transmission of body shape. The sire (center, surrounded by black line) is surrounded by his sons, all of which exhibit the characteristic body shape.

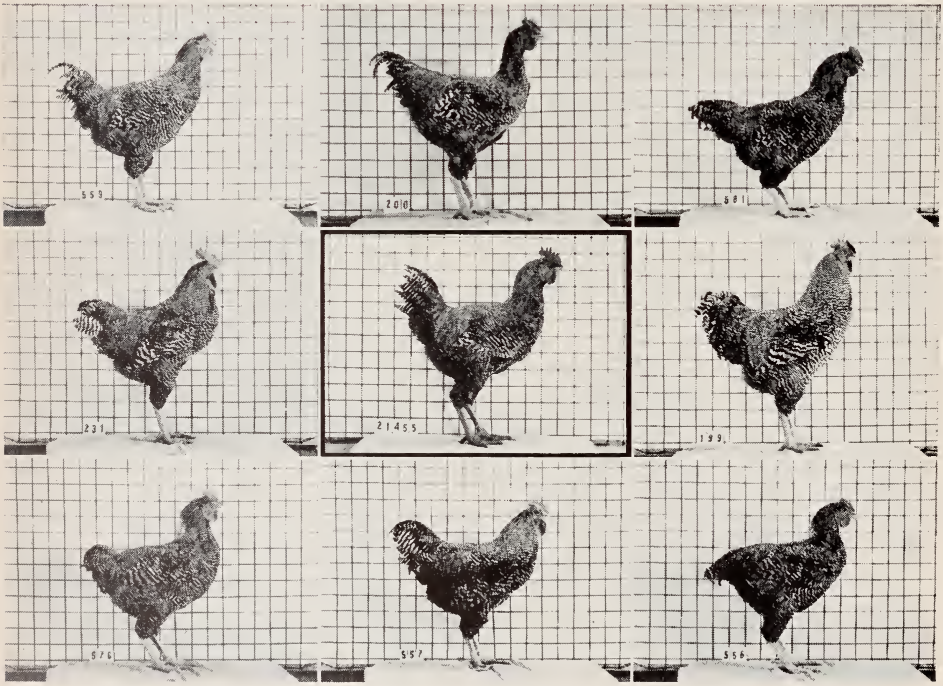

Fig. 5. Hereditary transmission of body shape. Compare these birds with their sire (center) and with the birds in Fig. 4. (Figs. 4 and 5 courtesy of Maw and Maw, 1938.)

over the breast at an early age and retain this characteristic throughout life; the American and English breeds do not reach the most desirable shape till maturity, though they present a fair carcass during growth. Such breeds as the Brahmas and the Jersey Black Giants are of extremely poor shape in early growth, and achieve desirable conformation only when full-grown. Figure 6 illustrates the conformation of adult females of some of the common breeds of poultry.

The second difficulty arises from the fact that at the present time only subjective evaluation of the merit of a live bird can be made. As already mentioned, no practicable methods of precise measurements on living birds which would describe the degree of excellence of the dressed carcass are as yet available. Although several methods have been proposed, none has proved to be accurate or simple enough to be practical.

Jaap and Penquite (1938) have suggested the use of various ratios of linear skeletal measurements to body weight as criteria of conformation. Although they have claimed that such ratios can be used in selection for improved shape, neither Scott (1940) nor Poley and his co-workers (1940) have found their ratios to be adequate measurements of the desirability of the carcass. Jaap (1941) has shown that the percentage of edible flesh is not particularly closely associated with the shape of the bird. Similarly Maw and Maw (1939) in noting a relation between certain body measurements and fattening gains, found the correlations between proportion of edible flesh and various body measurements to be very low.

It seems then that selection for improved conformation does not lead to the production of a carcass with more meat. Improvement in conformation really refers more to vague aesthetic standards by which the consumer judges the attractiveness of a dressed bird than to the amount of meat on a carcass. Attempts to put these more or less subjective notions on a measurable basis include in addition to the work already cited, a measuring device prepared by Dolecek and his associates (1941). A dial involving readings of three measurements for turkeys is available, and similar devices for chickens may be constructed. The measurements taken in such a manner are, however, not too closely related to visual

Fig. 6. Representative females of 3 breeds: from top, Barred Plymouth Rocks; Single Comb Rhode Island Reds; Single Comb White Leghorns.

standards of desirability. Perhaps eventually more workable quantitative methods will be found. Meanwhile visual evaluation of over-all shape appears to be a technique that is definitely usable.

Breast width. One component of shape can be measured with greater precision than the linear measurements outlined above—this is breast width. Since breast width is an important trait in the general impression of conformation, a breeder is justified in using it as a measurable criterion of selection.

Breast width can be measured in any one of several ways: with a soldering wire shaped to the breast and transferred to a ruled sheet to obtain the actual width; with calipers which measure the width at a fixed point (such as 1 or 2 cm. above the keel); with calipers at a point above the keel equal to about one-fifth of the body depth.

As stated, breast width has intermediate heritability, and while individual selection for this trait is not as efficient as combined individual and family selection, it can still be reasonably effective.

Edible flesh percentage. The different parts and organs of a bird do not grow at the same rate. As a result the percentage of the carcass which forms the edible flesh, the viscera, and the offal changes with age. Table 3 taken from Mitchell, Card, and Hamilton (1926) illustrates these changes in White Plymouth Rocks as the birds increase in weight from ½ to 7 pounds. It is questionable whether selection for a higher percentage of edible flesh can be successfully incorporated in a breeding program until more information on the subject is available.

Fat in the muscles. The amount of fat in the flesh of chickens undoubtedly affects the flavor. The fatness of the bird is also used in grading birds for market; hence, the amount of fat in the muscles is of considerable interest.

All analyses of the muscles agree in showing that the breast muscles contain less fat than the leg muscles; the other edible portions of the carcass contain more fat than the leg muscles.

Harshaw (1938) found no consistent increase in percentage of fat with increasing age in crossbred cockerels, although fattening caused a definite increase in amount of fat. This increase in the breast and the leg muscles was roughly proportional to the fat already present in these structures. It was, however, proportionately greater in other edible portions of the carcass. The chemical composition of

TABLE 3

Percentage Composition of White Plymouth Rock Carcasses at Various Weights*

Slaughter weight	Age	Empty weight	Offal	Viscera	Dressed carcass	Edible flesh and edible viscera
pounds	days	grams	per cent	per cent	per cent	per cent
0.5	29	216	19.2	19.7	54.2	34.5
1.0	43–57	423	18.7	22.1	58.1	41.1
1.5	71	637	19.5	18.2	58.7	41.5
2.0	103	967	18.7	16.2	59.9	40.7
3.0	117	1,305	20.0	14.3	62.2	43.0
4.0	169	1,725	20.6	12.6	64.3	42.2
5.0	177	2,156	20.6	12.9	64.5	43.3
6.0	250	2,509	19.7	12.0	65.6	45.9
7.0	324	3,182	17.8	9.9	69.4	50.4

* Data from Mitchell, Card, and Hamilton (1926).

TABLE 4

Chemical Composition of the Edible Portion of Crossbred Cockerels Which Were 12 Weeks Old at Start of 2-Week Fattening Period*†

	Protein		Fat		Ash		Water	
	Before fattening	After fattening	Before fattening	After fattening	Before fattening	After fattening	Before fattening	After fattening
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Breast muscle	23.7	23.9	0.39	0.84	1.24	1.18	74.8	74.1
Leg muscle	20.9	20.0	1.55	3.82	1.14	1.04	76.0	74.7
Remaining edible portion	21.0	16.2	5.9	24.5	1.04	0.76	71.0	57.6
Total edible portion	21.7	19.4	2.7	11.5	1.13	0.96	74.0	67.6

* Data from Harshaw (1938).
† The cockerels were F_1's from matings of females from Barred Plymouth Rock × Rhode Island Red to White Leghorn males.

one of the groups reported by Harshaw is shown in table 4.

Mitchell, Card, and Hamilton (1926, 1931) found that White Leghorn cockerels had a greater percentage of fat in the entire bird and in samples of flesh and edible viscera of cockerels weighing 2 to 4 pounds than in smaller or larger birds, whereas the percentage of fat in White Plymouth Rock cockerels continued to increase to the maximum average weight of 7 pounds. Pullets had a higher percentage of fat than cockerels at about 2 to 3 pounds and the percentage of fat increased with an increase in weight.

Table 5 shows that the percentage of dry substance increases as the birds grow from 1 to 3 pounds in weight. There is an increase in ether extract in Leghorns, the increase being greatest from 1.5 pounds' to 2 pounds' live weight. Assuming that the data for crude fat obtained in 1926 can be compared with those for ether extract obtained by the same analytical methods in 1931, the data show that the White Plymouth Rocks have a higher

TABLE 5

Dry Substance and Ether Extract (Crude Fat) in the Carcasses of Chickens at Different Ages*

Body weight	Cockerels				Pullets			
	Single Comb White Leghorns		White Plymouth Rocks		Single Comb White Leghorns		White Plymouth Rocks	
	Dry substance	Ether extract	Dry substance	Crude fat	Dry substance	Ether extract	Dry substance	Crude fat
pounds	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
1.0	26.84	2.50	26.96	5.88	27.93	2.53	....	....
1.5	30.84	3.68	30.13	7.34	29.53	3.86	....	....
2.0	33.39	5.48	31.50	8.60	33.39	6.47	31.89	8.82
3.0	32.78	5.88	32.41	7.18	37.50	11.22	34.92	9.97

* Data from Mitchell, Card, and Hamilton (1926, 1931).

percentage of fat than White Leghorns of corresponding weight. The higher percentage of fat in White Plymouth Rock cockerels is apparently due to a greater deposition of fat around the muscles and in the fat depots but not in the muscles themselves. The apparent difference in the percentage of fat in the flesh of these two breeds suggests that inherited differences may be involved, but no proof of this contention is available at the present time.

These are the factors influencing the marketable qualities of birds

Rate of feathering. When the chick hatches it is covered with down and has a variable number of flight feathers in the wing, and tail feathers in the case of Leghorns or early-feathering strains of other breeds. The body feathers grow in later, those of the shoulder being fully present at 1 week of age in early-feathering strains, whereas those on the head do not appear on these same birds until they are in their third week of age. The difference for a single feather tract between the earliest- and the latest-feathering birds amounts to as much as 8 weeks (Radi and Warren, 1938).

The down is replaced by chick plumage. The chick feathers are, in turn, replaced by juvenile, and finally by adult feathers. Four successive molts have been assumed to take place in White Leghorns on the basis of experimentally dyed feathers (Rice, Nixon, and Rogers, 1908). The number of plumages differs in the various feather tracts. This is shown in table 6, based on the observations made by Chu (1938) on Brown Leghorns. In some feather tracts (for example, on the back) there were six plumages—down, chick, three generations of juvenile feathers, adult; in others (on the thigh) three plumages—down, chick, adult. The second generation of remiges (primaries, secondaries) and rectrices (tail feathers) grew in when the birds were from 5 weeks to 6 months old and were mainly adult in form.

In White Leghorns some molting occurs before 6 weeks of age, but mainly new feathers are added. At about 12 weeks of age another major peak in molting occurs, but molting is to some extent continuous (Marble, 1934). Rate of growth is not reduced during the peaks in molt. In the strains and breeds studied by Radi

TABLE 6

Age at First Appearance of Feathers in Various Feather Tracts of the Brown Leghorn*

Part	Chick plumage	Juvenile plumage			Adult plumage
		First	Second	Third	
	days	weeks	weeks	weeks	weeks
Wing bow	8	6	9	13	16
Shoulder	..	5	8	12	14
Breast	13	6–7	10	..	12
Back	17	8	12	14	18
Saddle	..	8	10	14	18
Cape	21 +	5	10	16	18
Thigh†	13	..	..	..	..

* Data from Chu (1938).
† No juvenile plumage, chick plumage directly replaced by adult plumage.

and Warren (1938) little molting—in the sense of dropping feathers and replacing them—apparently occurred before 9 weeks of age. The published information points to the possibility that there is considerable variation in the age at which different plumages appear and are replaced, if not in the number of successive plumages, in different breeds or strains.

Rate of feathering depends to some extent on the growth and general well-being of the bird. This is shown by the relatively slow feathering of runty birds where the same factor—usually unfavorable environment—causes slow growth and slow feathering. Well-grown birds of normal size also differ among themselves in rate of feathering and such differences have been

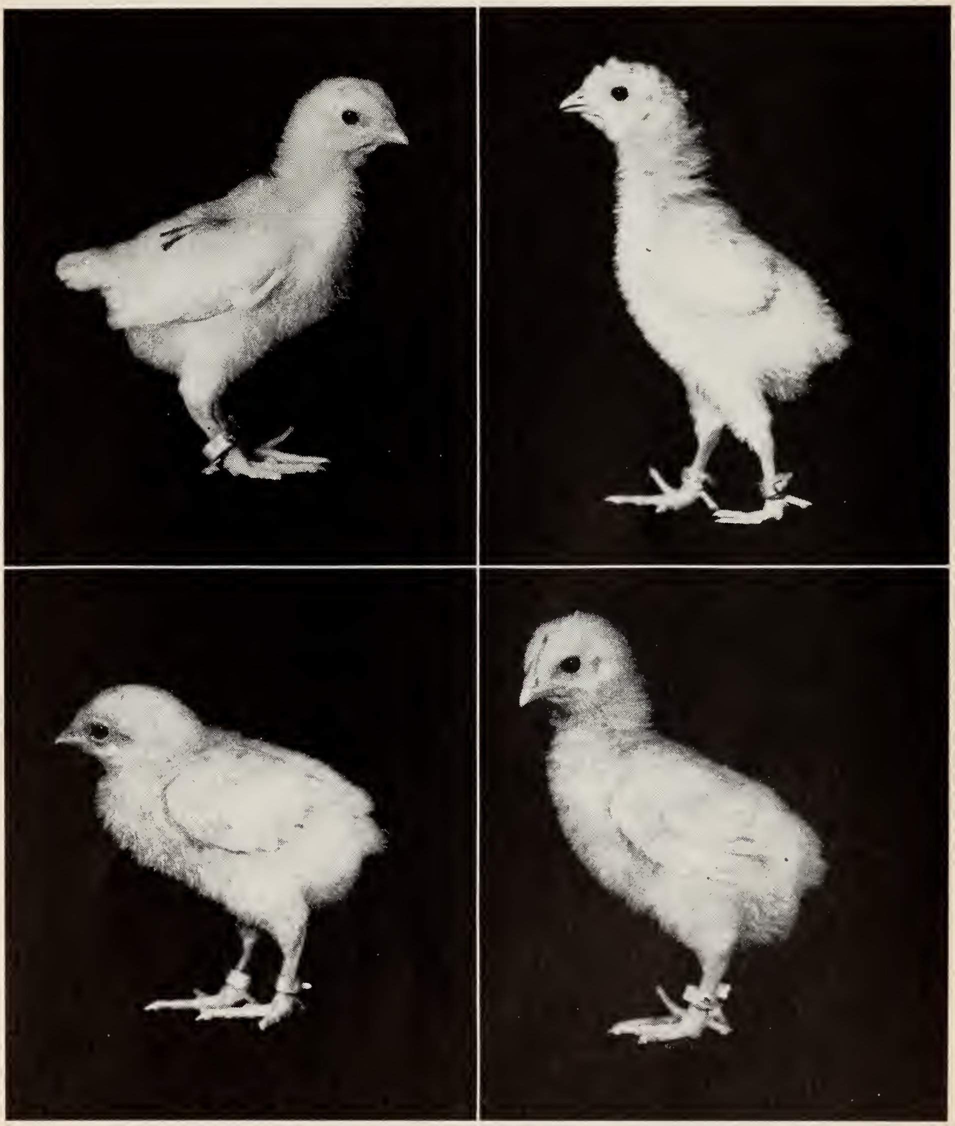

Fig. 7. Inheritance of sex-linked factor for slow feathering. Top left to right: male and female chicks from mating of Jersey Black female to White Leghorn male. Lower: male and female chicks from a reciprocal cross. (Reproduced from Jull, 1940, courtesy of John Wiley and Sons, Inc.)

shown to be inherited. In these well-grown birds there is little relation between rate of growth and feathering.

Differences between breeds. The best known inherited differences between breeds in rate of feathering are determined by sex-linked genes (Warren, 1925). Rapid-feathering breeds such as Leghorn carry a sex-linked recessive gene for rapid feathering. Such breeds show some development of the flight and tail feathers when hatched, and these are well developed at 10 days of age, the primary feathers extending to or beyond the posterior end of the body. On the other hand, slow-feathering breeds, such as Jersey Black Giants, have no tail feathers until they are at least 16 days old, and many do not have tail feathers until they are 4 or 5 weeks old. The primary feathers are shorter at 10 days of age and the feathers on the back develop later in the Jersey Black Giants than in Leghorns (fig. 7).

Most of the breeds used for meat production are slow feathering. In recent years desirable strains of early-feathering birds of these breeds, such as the New Hampshire, Rhode Island Red, and Plymouth Rock, have been established.

Differences within varieties. Although the White Leghorns are early-feathering, slow-feathering individuals are occasionally observed. The inheritance of slow feathering in one strain was studied at the Kansas Station (Warren, 1933) and found to be a simple autosomal (non-sex-linked) recessive to early feathering. The chicks with retarded feathering had primary flight feathers of normal length for Leghorns but no tail feathers at 10 days of age. All except the first three or four secondaries were also retarded at 2 weeks of age. At 1 day of age the early-feathering chicks had 6 or more well-developed primaries, while retarded chicks had not more than 3.

Slow-feathering Leghorn chicks (fig. 8) at the Western Washington Experiment Station (McClary and Bearse, 1941) differed from the chicks with retarded feathering reported from Kansas by having no secondaries when hatched. The primary flight feathers and body feathers grew slowly to 4 to 6 weeks of age. At 12 weeks slow-feathering birds of this type are indistinguishable from normal early-feathering Leghorns. Slow feathering, like the retarded type studied at Kansas, is conditioned by a single autosomal gene, recessive to the gene for rapid feathering. Retarded and slow feathering are undesirable characters, and should be eliminated whenever they occur.

More recently other genes affecting feathering adversely have been discovered. Although differing in some respects from those described, the general problems of selection against them are of the same nature.

Differences in back feathering. The simplest method of insuring well-feathered chicks at broiler age would seem to be to introduce the recessive sex-linked gene for early feathering into all breeds and varieties used for meat production. Considerable success has, however, been attained by selecting for early feathering on the back and other parts of the body in strains of birds carrying the dominant sex-linked gene for slow feathering. These strains apparently carry genes which modify the expression of feathering to such an extent that some birds feather out more rapidly than others. Work with Rhode Island Reds at the Kansas Station (Radi and Warren, 1938) has shown that selection of the earlier-feathering birds for breeding is an effective method of improving rate of feathering. Most of the improvement occurred in the first two years of selection.

Work in Sweden (Axelsson, 1932) indicates that such slow-feathering breeds as the Rhode Island Red and Barnevelder differ in rate of feathering, the differences being due to both sex-linked and autosomal genes. Axelsson concluded that the birds could be more accurately classified at 33 than at 89 days of age and that in this case rapid feathering was dominant

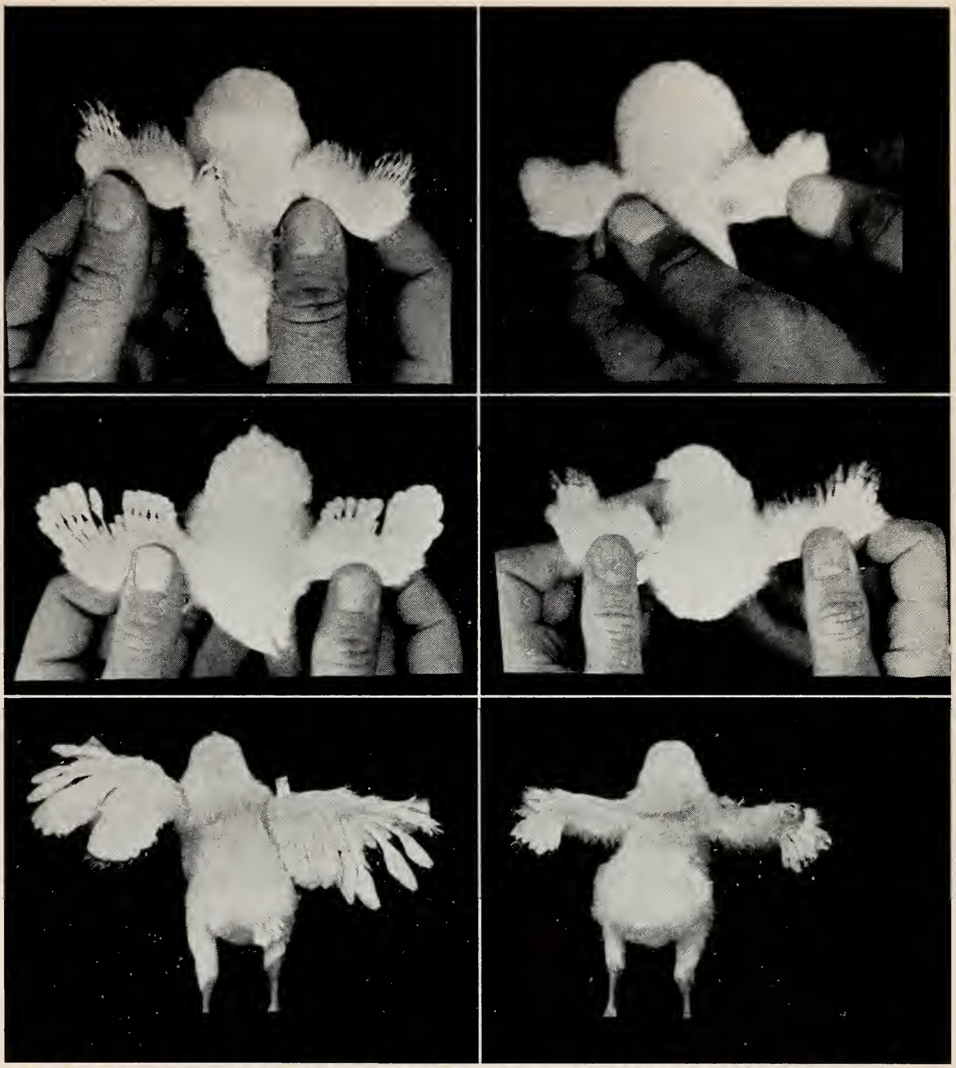

Fig. 8. Comparison of slow and normal feathering in White Leghorn chicks. Top to bottom left: normal feathering at 1 day, 4 days, 7 days. Top to bottom right: slow feathering at same ages. (Courtesy C. F. McClary, Western Wash. Exp. Sta.)

to slow feathering. Lloyd (1939) and others have also worked on rate of feathering in the general-purpose breeds. In all cases favorable results—earlier feathering on different parts of the body resulting in more complete feathering of birds at broiler or fryer age—have been obtained. The exact mode of inheritance has not been worked out, but it seems evident that there are several autosomal genes that modify the expression of the sex-linked dominant slow feathering which is characteristic of most strains of the heavier general-purpose breeds.

Probably the most favorable period for selection in strains of the sex-linked slow-feathering type is after an age at which part of the flock shows considerable feather growth but before a majority are completely feathered. Certainly the selection for feathering should be made before any of the chicks reach a marketable

weight. This would mean selection for rate of feathering at 6 to 8 weeks of age or earlier.

Breast defects. The commonest breast defects are crooked keel and breast blisters. Others, for instance, split keels, presumably an accidental developmental deformity, are so rare that they are of negligible economic importance and will not be discussed in this bulletin.

Crooked keel may result from nutritional deficiencies, particularly insufficient minerals or vitamin D in the diet of chicks not exposed to sunlight; from too early roosting on narrow roosts (for instance 1-inch roosts at 3 to 8 weeks of age) ; and from a hereditary tendency to develop crooked keels. Crooked keels develop most frequently between 6 and 16 weeks of age (Warren, 1937). The ash content of crooked keels is lower than that of straight keels at 8 weeks of age, although there is no difference in the ash content of the leg bones from these two groups.

The influence of hereditary factors on the percentage incidence of crooked keels is shown in the results of reciprocal matings of two Leghorn strains (Warren, 1937) :

	Per cent with crooked keels	
	Females	Males
Strain A	44	50
Strain C	12	21
Strain C female × strain A male	30	39
Strain A female × strain C male	19	22

It will be observed that strain A had a much higher incidence of crooked-keeled birds than strain C and that the offspring from crosses between these strains were intermediate. The differences in the reciprocal crosses presumably indicate genetic differences in the stock used involving autosomal, not sex-linked genes. Were the differences due to sex-linked genes, the females, but not the males, from reciprocal matings should have differed in the incidence of crooked keels. Since the males from reciprocal matings differed just as much as the females in the percentage of crooked keels it seems probable that the results obtained were due to genetic differences in the parent stock used for the reciprocal matings.

Carstens and Prüfer (1939) and others have confirmed the work of Warren showing that there is an inherited tendency to develop crooked keels. Obviously, only straight-keeled birds should be used for breeding. Furthermore, it is not advisable to roost birds early, and when they are started on roosts, the roosts should be at least 2 inches wide, and smooth. Care should also be taken to feed an adequate diet (fig. 9).

Breast blisters are characterized by the collection of viscous fluid under the skin over the keel. Small blisters usually are not noticed and have no effect on the market value of the meat birds, but large blisters detract from the appearance of the birds and thereby reduce their market value. The fluid can be removed from large blisters without leaving an unsightly scar by making an incision through the skin behind the wing and forcing out the fluid. Prevention is a more desirable method of avoiding breast blisters, but not enough is known about their cause to do this effectively.

According to Hodgson and Gutteridge (1941) the contents of blisters are sterile, so they are not caused by infection. Furthermore, the age at starting to roost, the size or shape of roosts, complete elimination of roosts to 16 weeks of age, and the

Fig. 9. Keels of 8-week-old chicks raised on a diet deficient in vitamin D. Top row from crooked-keel strain; bottom row from straight-keel strain. (Courtesy of Warren, 1937.)

use of deep litter have no influence on the incidence of breast blisters. Birds reared on wire do, however, have a higher incidence of breast blisters than floor-reared birds. Blisters first developed at 8 to 10 weeks of age in 1940, but if the data given by Hodgson and Gutteridge for that year are reasonably typical, very few occur before the 12th week and most of them not until after the 15th week. The age incidence does vary, however. The problem is usually not serious in broiler or fryer production if the birds are marketed when they weigh 3 pounds or less, but may cause heavy losses when roasters are produced. Roasters are now commonly raised on the floor (not on wire) without roosts.

Birds with blisters are slightly, but not significantly, heavier than those without blisters, the two groups overlapping in weight. Few blisters develop on White Leghorns or on females of the heavier breeds, but a high percentage of the males of the various American and English breeds sometimes develop breast blisters (table 7, next page).

Differences were observed in the incidence of breast blisters in sire families. Hodgson and Gutteridge state, without

TABLE 7

Influence of Breed and Sex on the Expression of Breast Blisters*

Breed	Year	Males		Females	
		Number of birds observed	Per cent blistered	Number of birds observed	Per cent blistered
Barred Plymouth Rock.......	1939	486	45.4	549	3.1
Barred Plymouth Rock.......	1940	407	38.5	626	1.1
Single Comb White Leghorn..	1939	225	2.6	331	0
Single Comb White Leghorn..	1940	214	2.8	341	0

* Data from Hodgson and Gutteridge (1941).

proof and counter to the results reported by them, that breeding to eliminate the defect is not likely to prove effective. While it may prove difficult to eliminate breast blisters by using for breeding only birds free from breast blisters out of families with a low incidence, that method seems to offer some hope of reducing occurence of the defect.

Flesh pigments. Dark meat differs from white or light-colored meat in the amount of the pigments called myoglobin and cytochrome (Needham, 1926). In addition to these pigments, birds that have black coloring in the feathers may also have it in the flesh, particularly in the abdominal region. Black pigment does not occur in the flesh of white-plumaged birds nor in the flesh of birds with relatively light plumage, such as typical standard New Hampshires or the various buff varieties.

Black pigment does no harm except to detract from the appearance of the bird. Because of the unattractive appearance some fastidious people will not buy birds exhibiting this pigment but will pay a premium for well-fleshed birds free from it. Buyers in California generally do not discriminate against birds with black pigment; such birds command the same price as other colored birds of similar size and condition but free from black pigment in the flesh.

By using for meat production birds that have plumage free from black color (white or light red plumage) the unsightly black pigment in the flesh can be avoided.

Economy of gain. The producer of poultry meat is interested not only in the type and quantity of yield, but in the cost at which such yield is obtained. Aside from the original price paid for day-old chicks and purely managemental costs, this question resolves itself into the efficiency of food utilization by the growing birds. In a crude way, efficiency can be measured by the ratio of pounds of gain in weight over pounds of feed consumed in a given period. Actually a part of the food consumed by an animal is used for maintenance and the remainder is used for growth. For practical purposes the "total weight efficiency" (the measurement described above) may be used provided comparison between chickens of the same age and size is made. This is due to the fact that the maintenance requirements depend on a function of body size, so that if the total weight efficiency of two animals is compared, any size difference between them will introduce an error.

Thus, Hess, Byerly, and Jull (1941) have studied the total weight efficiency of Barred Plymouth Rock broilers originating from different sires and found dif-

TABLE 8

Growth of Crossbred Cockerels (Barred Plymouth Rock Females × Rhode Island Red Males) in Relation to Feed Consumption*

Age	Number of birds	Body weight		Feed consumption		Gain per gram of feed	
		Average	Gain per period	Per period	Total	Per period	Cumu-lative
weeks		grams	grams	grams	grams	grams	grams
0........	40	34.8	....	....	....	....	....
2........	40	82.3	47.5	136.1	136.1	.349	.349
4........	39	225.6	143.3	257.4	393.5	.557	.485
6........	39	399.4	173.8	536.4	929.9	.324	.392
8........	39	656.6	257.2	814.1	1,744.0	.316	.357
10........	39	924.2	267.6	1,116.5	2,860.5	.240	.311
12........	38	1,225.7	301.5	1,288.0	4,148.5	.234	.287
14........	38	1,629.7	404.0	1,406.1	5,554.6	.287	.287
16........	38	1,933.0	303.3	1,309.5	6,864.1	.232	.277
18........	38	2,157.4	224.4	1,647.2	8,511.3	.136	.249
20........	38	2,435.5	278.1	1,715.9	10,227.2	.162	.245
22........	37	2,744.9	309.4	1,745.1	11,972.3	.177	.235
24........	37	2,926.9	182.0	1,764.2	13,736.5	.103	.218

* Data from Jull and Titus (1928).

ferences between them. However, it is not possible to say whether or not such differences reflected only differences in rate of growth or also the variation in the real efficiency (efficiency of gain, independently of maintenance). Hess and Jull (1948) and McCartney and Jull (1948) have obtained results which, according to them, show that inherited differences in the real efficiency do exist.

From the standpoint of the practical breeder, it should be remembered that the total weight efficiency definitely decreases with age. As a particular bird increases in size more and more of the feed it consumes is required for maintenance, so that the gain per pound of feed is reduced. Therefore the sooner the animal reaches marketing weight, the more profitable it is.

Table 8, prepared from data presented by Jull and Titus (1928), illustrates this particular point. It is readily seen that the gain per unit of feed consumed decreases with age (last two columns of the table). Titus (1940) has presented a graph which shows this decrease to follow a straight line (fig. 10).

Obviously the gain per pound of feed consumed is so low for birds of roaster size that they become unprofitable to produce unless there is a premium for larger birds.

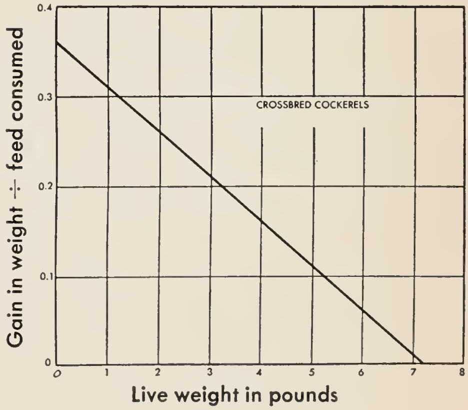

Fig. 10. This shows relation of weight gains to feed consumption. (Adapted from Titus, 1940.)

Crossbreeding may or may not prove beneficial in meat production

Crossbreeding is the mating of birds from different breeds, such as Plymouth Rock × Rhode Island Red, Cornish male × Plymouth Rock female, and others. It is commonly used also to denote matings of birds from different varieties, such as White and Barred Plymouth Rocks. Outbreeding is the mating of unrelated birds of the same variety.

Crossbreeding is widely used in the production of poultry for meat. In general the results obtained vary according to the genetic constitution of the breeds and strains crossed. For this reason there may be important differences in the results obtained from crossing two different strains of one variety with a strain of another variety.

Hybrid vigor. When different breeds are crossed it is frequently observed that fertility, hatchability, livability, and rate of growth are increased. This occurrence, known as heterosis, or hybrid vigor, is usually the only valid reason for crossbreeding. If no hybrid vigor is obtained when breeds are crossed, there is usually no advantage in making the cross. The increasingly popular exception to this may be the crossing of Cornish males on females of other breeds to produce a more attractive carcass.

The crosses that have been made may conveniently be divided into three groups: (1) crosses of comparatively small breeds, such as the Leghorn, with heavier breeds, such as the Plymouth Rock, New Hampshire, Rhode Island Red, Jersey Giant, Australorp; (2) crosses between the heavier breeds or different varieties of those breeds; (3) crosses of Cornish or other heavy nonfighting game-type males onto females of other breeds. The Cornish females are not used because they are usually poor layers.

The results of crossbreeding may be considered in relation to fertility, hatchability, chick mortality or survival, growth of the chick, feed required per pound of gain, and feathering.

The data in tables 9 and 10 indicate that crossbreeding has little or no effect on fertility where average fertility is obtained in the strains used.

On the other hand, hatchability generally is improved by crossbreeding. This has been shown by the work of several investigators (Warren, 1930; Byerly, Knox, and Jull, 1934; Funk, 1934; Hess, Byerly, and Jull, 1941). At the National Research Center (Knox, 1939) it was found that if the hatchability of the parent breeds was low there was a considerable increase from crossbreeding, whereas crossbreeding resulted in little or no increase in hatchability when the hatchability of eggs from the parent breeds was high.

The mortality to 8 weeks among crossbred chicks is lower, on the average, than the mortality among the chicks of the breeds and strains crossed. There are exceptions (Bice and Tower, 1939; Horlacher, Smith, and Wiley, 1941) but the best comparative data (Warren, 1930) where males of the same breed were alternated with males of a different breed, leave no doubt that on the average a higher percentage of the crossbred chicks survive. Here, as in the case of hatchability, there is considerable improvement in survival if the viability of the parental strains crossed is low; but little, or in some cases, no improvement is obtained by crossing if the viability of the parental strains is high.

The rate of growth of crossbred chicks on the average exceeds that of the parent breeds to broiler or fryer weight when heavy breeds are crossed. When Leghorns and general-purpose breeds are crossed the crossbreds may exceed both parental varieties to 8 or even 12 weeks of age, but after that the heavier breeds are likely to weigh more. The results of cross-

TABLE 9

Summary of Results of Crossbreeding in the Arkansas Experiments*

Breeds or crosses	Fertile eggs	Hatch of fertile eggs	Chicks surviving to 8 weeks of age	Average weights at 8 weeks	Average weights at 12 weeks	Feed per pound of gain to 12 weeks	Bare-back chicks at 8 weeks
	per cent	per cent	per cent	pounds	pounds	pounds	per cent
Leghorn × Leghorn	89.7	65.7	92.5	1.20	2.17	4.66	1.45
Leghorn × Cornish, Wyandotte, or Australorp	76.5	85.0	89.3	1.21	2.25	4.41	12.12
Heavy breeds†	83.6	80.3	86.9	1.18	2.24	4.84	12.67
Heavy crossbreds	82.4	81.7	94.1	1.28	2.42	4.34	25.90

* Data from Horlacher, Smith, and Wiley (1941).
† Rhode Island Reds, Rhode Island Whites, Barred and White Plymouth Rocks.

ing the Japanese Shamo Game or the Dark Cornish on other breeds may be expected to be the same so far as growth is concerned as if one of the commoner American or English breeds were used. The breast conformation of the crossbreds will, however, resemble that of the Cornish or Game breed and they will have the compact feathering characteristic of the Cornish (Jaap, 1941).

Hybrid vigor, as measured by growth, will depend on the strains crossed (Knox, 1939). The most rapid-growing strains of birds do not always give the best results when crossed. Nevertheless, when the same male was crossed with females of two different breeds the progeny of the hen from the more rapid-growing breed made the better gains to 8 weeks of age (Warren, 1930).

Crossbreds utilize feed more efficiently on the average than birds of the parental strains (Hess, Byerly, and Jull, 1941). The data in tables 9 and 10 show also that the crossbreds required less feed to produce a pound of gain. They may use feed more efficiently than purebreds because of more rapid growth and not because they are more efficient converters of feed into flesh than the parental breeds, al-

TABLE 10

Summary of Results of Crossbreeding in the Hawaii Experiments*

Breeds or crosses	Fertile eggs	Hatch of fertile eggs	Chicks surviving to 8 weeks of age	Average weights at 8 weeks	Feed per pound of gain to 8 weeks
	per cent	per cent	per cent	pounds	pounds
Leghorn × Leghorn	75.6	53.6	86.6	1.29	3.97
Leghorn × Japanese Shamo Game	76.9	65.7	92.7	1.46	2.58
Heavy breeds†	76.9	60.3	92.4	1.37	3.41
Rock and Red females × Shamo Game males	74.4	63.0	96.3	1.50	2.67

* Data from Bice and Tower (1939).
† Japanese Shamo Games, Barred Plymouth Rocks, and Rhode Island Reds.

though that is a possibility (see the section "Economy of Gain"). It may be assumed, nevertheless, that rapid growth and low mortality are the most important factors in efficient use of feed by meat birds.

Leghorns have fewer bare-backs than the crossbreds or heavy breeds (see data of Horlacher, Smith, and Wiley in table 9), as would be expected. Crossbreds from Leghorn hens mated to heavy-breed males feather out at an earlier age on the average than crossbreds between heavy breeds. The results apparently depend partly on the heavy breed used, since the crossbreds from Leghorn female × Australorp male were slower in feathering than most of the crossbreds between heavy breeds. The slowest-feathering birds were from White Wyandotte hens mated to Rhode Island Red males (82.81 per cent bare-backs at 8 weeks of age), a result that may again reflect strain, rather than breed differences, although the progeny of the reciprocal cross had very few bare-backs (4.05 per cent) at 8 weeks. Apparently hybrid vigor, as such, is not a factor in rate of feathering.

Maturity and egg production. Age at first egg is an inherited character probably determined by both sex-linked and autosomal genes. Early sexual maturity is dominant to late sexual maturity; hence, it would be advisable to use males from early-maturing strains if the pullets are to be kept for egg production. Actually, however, egg production depends on so many nonsex-linked factors that no single one of them has a major effect. The reports of Knox (1939) and others indicate that the crossbreds are usually intermediate but that sometimes they exceed both parents in the production of eggs.

The average annual egg production of hybrids and the parental breeds as reported by Warren (1930) is shown in the figures given below.

While some crossbreds are excellent layers, others are relatively poor; this varies with the strains crossed. The crossbreds produced from unimproved lines of purebreds are usually poorer layers than birds from superior strains of the more popular breeds.

	Eggs per bird
White Leghorn	173.8
Jersey Black Giant	162.3
Hybrids	212.9
Rhode Island Red	168.9
White Leghorn	211.6
White Leghorn female × Rhode Island Red male	198.7
Rhode Island Red female × White Leghorn male	214.6

Similarly Knox (1939) presented the following figures:

	Eggs per bird
White Leghorn	201.3
Rhode Island Red	201.5
Crosses involving light breeds	139.4
Crosses involving heavy breeds	165.7

Here are some breeds and crosses recommended for meat production

The breeds used and the crosses made will depend on the market type, whether broiler, fryer, light or heavy roaster, and on the market outlet. On some California markets birds with colored plumage command a higher price during all or most of the year. As long as this prejudice exists and affects prices, it should be considered. However, it is advisable to avoid birds with too much black in the feathers.

For broilers. White Leghorn cockerels make satisfactory broilers; so do crossbreds from Cornish, Barred Plymouth Rock, New Hampshire, Rhode Island Red males or males from similar breeds mated to White Leghorn females. Leghorn cockerels tend to become staggy if held too long, and are better suited for broilers than fryers. The crossbreds also are better suited to broiler than fryer production since their rate of growth is slower than that of the heavy breeds after they attain weights of about 2 pounds.

These crossbreds will, however, make excellent fryers or light roasters, although they are perhaps less desirable than crossbreds from heavy breeds. They are not likely to be as economical as heavy roasters, as the heavier breeds or their crossbreds, because they will usually be intermediate in weight between the heavier parental breed and the Leghorn. When a lower price is paid for white-plumaged birds, the initial cost of Leghorns or their crossbreds should be sufficiently lower to offset the difference.

The heavier breeds, such as Rhode Island Reds, New Hampshires, Barred Plymouth Rocks, or crossbreds between these breeds, make excellent broilers although it may not be economical to market them as light broilers. Good broilers can also be obtained by crossing these breeds on White Plymouth Rocks or strains of White Wyandottes that carry a recessive and not the dominant gene for white plumage.

Good broilers can also be obtained by mating nonstandard—that is, normally long-legged—White, Red, or White Laced Red Cornish males to females of the breeds mentioned. An early-feathering strain should preferably be used for at least one of the parental breeds and varieties crossed. By this is meant a strain that carries the recessive sex-linked gene for early feathering found in Leghorns and other early-feathering breeds.

For fryers or light roasters. The heavier breeds and the crossbreds obtainable from them make excellent fryers. These include the New Hampshires, Rhode Island Reds, Barred Plymouth Rocks, and crosses of these with recessive white varieties such as the White Plymouth Rock, White Wyandotte, Rhode Island White. Other breeds and crossbreds include the Jersey Black or White Giants. The blacks do not always dress out so attractively as birds with less black pigment, and desirable strains from the standpoint of growth, feathering, livability, and egg production are not always available. For California, Jersey White Giants have the disadvantage of white plumage and are not readily available.

In addition several other breeds are used for producing fryers. These include the Australorp, the Buff or White Orpington, and the Sussex. All are white-skinned birds and should not be used if there is any discrimination against such birds in the market where they are sold. This also applies to the white-plumaged varieties. The Light Sussex usually make good fryers and are suitable for crossing where white-skinned birds are acceptable. Some strains of Australorps and Orpingtons, however, tend to be deep- and narrow-bodied and to fill out slowly on the breast; such strains should not be used.

Crossbreds from suitable strains of Cornish males mated to females of the better heavy breeds, such as the Barred

or White Plymouth Rock, Rhode Island Red, New Hampshire, and others, make good fryers and light roasters.

For heavy roasters and capons. Any of the breeds mentioned as suitable for fryer and light-roaster production can be used to produce heavy roasters or capons. The heavier breeds (Giants, Orpingtons) are sometimes preferred but reasonably heavy strains of any of the more popular heavy breeds—the Barred Plymouth Rock, New Hampshire, Rhode Island Red, their crosses or crossbreds from females of these breeds mated to Cornish males—are likely to prove better and more easily available. The only advantage that crossbreds are likely to possess over purebreds for heavy roaster or capon production is slightly higher hatchability and lower mortality. There is no advantage over good strains of purebreds in rate of growth and economy of gain such as there frequently is for broiler, fryer, and even light-roaster production.

Jeffrey (1938) has suggested that surplus Leghorn cockerels, particularly the later hatched birds, could profitably be marketed as light capons. Under California conditions it seems more profitable, however, to continue to market them as broilers.

These are the breeding standards for meat birds for California markets

Most of the birds raised primarily for meat production in California are marketed when they reach fryer or light-roaster weights. Leghorn cockerels are, of course, an exception, but they are a by-product from the raising of pullets for egg production. Few heavy roasters or capons are raised since they are likely to be less profitable than fryers or light roasters because of the larger amount of feed consumed per pound of chicken marketed—except under especially favorable conditions for their production. This means that the most popular market chicken is a full-feathered, well-fleshed bird with colored plumage and yellow shanks, weighing about 3 to 4 pounds.

California breeding methods can be the same, with slight modifications, regardless of whether the birds are to be marketed as broilers, fryers, or light roasters. For mass selection, the weight, feathering, and fleshing should be considered. The pedigree breeder will con-

TABLE 11

Suggested Weight Standards for Breeding Selection*

Age in weeks	Heavy breeds		Leghorns	
	Males	Females	Males	Females
	lbs.	lbs.	lbs.	lbs.
6	1.34	1.18	1.01	.89
8	1.90	1.71	1.60	1.33
10	2.88	2.50	2.11	1.65
12	3.46	2.96	2.79	2.14
14	....	3.32	....	2.50
16	....	3.75	....	2.75
18	....	4.21	....	2.95

* Data from Rosenberg, Palafox and Tanaka (1949).

sider these and also fertility, hatchability, mortality, and egg production. The following standards are suggested:

Fertility—90 to 95 per cent, according to the season.

Hatchability—80 to 85 per cent, according to the season.

Mortality to 8 weeks—less than 7 per cent.

Mortality to 20 weeks—less than 12 per cent.

Weights—as shown in table 11. At least one and preferably two weighings before 12 weeks of age should be made. The figures in the table may be used as a general guide, since they are subject to considerable variation owing to differences in management and nutrition.

Feathering—fully feathered at a weight of 1 pound.

Fleshing—sufficiently plump on the breast and otherwise well fleshed at from 1- to 4-pound weights to go into the top grade on the market.

Breast width—three-quarters of an inch, one-half of an inch above the keel near the front end.

Egg production—eggs to weigh 2 ounces each. The average per hen for the breeds should be: Single Comb White Leghorns, 200 eggs; Barred Plymouth Rocks, Single Comb Rhode Island Reds, New Hampshires, and similar breeds, 175 eggs; Cornish, 150 eggs.

It should be kept in mind that these are objectives and do not necessarily represent averages. The standards suggested are, however, frequently exceeded and are attainable. Standards for selection will, in most cases, have to be based on actual performance of the strain used. Having established standards, superior individuals from families that are better than average should be used for breeding.

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Suggestions for Further Reading

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1949. Fertility and hatchability of chicken and turkey eggs. xi + 423 pp. John Wiley, New York.
A comprehensive survey by ten collaborators of the various problems connected with commercial reproduction of poultry. The section on genetics and physiology should be of particular interest to the readers of the present bulletin.

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15m–1,'51(1280)W.P. 141

CONTENTS

Basic factors of heredity 4
California broiler production 6
Grades of California birds 6
Requirements for California meat birds 8
Establishing a breeding program 9
Mass selection 9
Pedigree breeding 10
Family selection 10
Degrees of heritability of some factors 11
Problems common to breeding programs 12
Factors affecting meat quality and quantity 13
Chick weight 13
Growth rate 13
Growth patterns 17
Season 17
Conformation 17
Breast width 20
Edible flesh percentage 20
Fat in muscles 20
Factors influencing marketable qualities 22
Differences between breeds 24
Differences within varieties 24
Rate of feathering 24
Breast defects 26
Flesh pigments 28
Economy of gain 28
Crossbreeding—effects 30
Hybrid vigor 30
Maturity and egg production 32
Recommended crosses 33
For broilers 33
For fryers and light roasters 33
For heavy roasters and capons 34
Breeding standards for California birds 34
Literature cited 35
Suggestions for further reading 37